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Current-Fed Switched Inverter With Coupled Inductor For Low Voltage Renewable System

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Abstract: **This paper presents a novel coupled inductor based high boost inverter topology which can be utilized in low voltage renewable systems where high voltage step-up is needed to interface with 110 Vt220 V AC systems. The proposed inverter possesses high boost ability with superior EMI immunity compared to a traditional voltage source inverter (VSI). Unlike the traditional VSI, the proposed inverter does not need dead time circuit for its switching signals as it utilizes shoot-through state of the inverter in its single-stage configuration. Insertion of shoot-through state also helps it to achieve high boost operation essential for renewable energy applications. The proposed inverter is derived from Current-Fed Switched Inverter topology. Apart from topology derivation, this paper describes the steady state analysis of the inverter and establishes the relation between input, DC-link, and AC output. An experimental prototype is built to validate the proposed inverter circuit. A 220 V (rms) AC is obtained from 52 V DC input to demonstrate its boost mode of operation.**

I. INTRODUCTION

Voltage source inverters are widely used in UPS, motor drives, grid connected and stand-alone renewable systems, etc. The main limitations of traditional VSI are:

1) The output AC voltage cannot be more than its input DC voltage as VSI is a buck inverter. Due to this reason a DC-DC boost converter stage is needed prior to the VSI to achieve step-up DC-AC inversion when the input DC voltage is limited like in the case of solar PV, fuel cell, etc. Commercially available solar PV panel voltage ranges from 12 V to 48 V typically whereas for fuel cells, it is typically between 24 V to 56 V. For this reason, a high step-up inversion is needed to connect the renewable sources to 110 V / 240 V AC systems which cannot be obtained from a VSI. 2) The upper and lower switching devices of any leg of the VSI cannot be turned on simultaneously thus requiring for a dead-time circuit which in turn contributes to waveform distortion. Although, adding dead-time in the switching signals cannot alleviate the chances of mis-gating or shootthrough due to spurious signals or EM! noise [1]. To eliminate these drawbacks of VSI, inverters like Z-Source Inverter (ZSI) [1], Quasi-ZSI (q-ZSI) [2], Switched Boost Inverter (SBI) [3]-[5], Boost-Derived Hybrid Converter (BDHC) [6], Trans-ZSI (T-ZSI) [7], etc., were proposed. These new-age inverters present single stage DC-AC inversion with high boost capability and utilize the shoot-through phenomenon in the inverter legs to provide superior EMI immunity. In the lines of these inverters, Current-Fed Switched Inverter (CFSI) was proposed [8]-[9] which provided high gain (same as ZSI) with the low passive component count. Due to the presence of input inductor, CFSI provided continuous input current property which is necessary for renewable applications. In all of the above mentioned inverters, shoot-through state imposes some restriction on the modulation index which limits them to achieve high overall input DC to output AC gain. Thus, in recent years, there is a constant effort among the researchers to increase the overall.

DC-to-AC conversion ratio of these shoot-through inverters by a) Modifying the pulse width modulation scheme so that the constraint on modulation index can be minimized. It has resulted in invention of new modulation techniques like Constant Boost Control, Maximum Boost Control schemes, etc.

b) Improving the boost factor (input DC-to-inverter input gain) of the inverters by using either passive network (switched capacitor, switched inductor etc.) or magnetic (tapped inductor, coupled inductor etc.) network. Nevertheless, inverters with low component count, continuous input current, low device stress are always an attractive option owing to their high efficiency, ease of integration with renewable sources, low device cost and device footprint. This paper presents a coupled inductor based high boost inverter topology derived from Current-Fed Switched Inverter (CFSI) which is named as Coupled Inductor based Current-Fed Switched Inverter (Trans-CFSI) as it utilizes energy transfer through the transformer action of the coupled inductor to achieve high boost. Like SBI, the proposed inverter uses an active network between the DC input and inverter bridge with one LC-filter pair. In the next section, CFSI topology is reviewed. Derivation of Trans-CFSI topology from

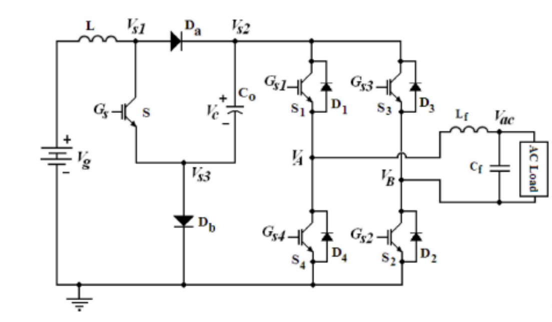
CFSI is discussed in section III along with its steady-state characteristics. the PWM control scheme of Trans-CFSI is described. The proposed inverter is verified with experimental results.

II. CFSI TOPOLOGY

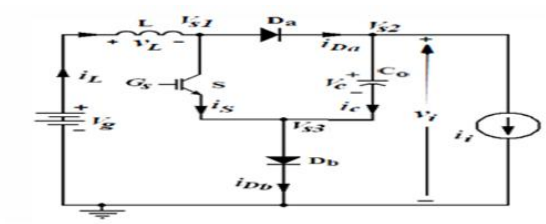
The circuit schematic of Current-Fed Switched Inverter (CFSI) is shown in Fig. 1 (a). CFSI provides high-boost operation similar to ZSI and q-ZSI utilizing the shoot through state of the inverter legs. The operating states of the CFSI can be broadly categorized into i) Shoot through state and ii) NonShoot through state, the later can be further be divided into active state (power interval of the inverter) and zero state (zero interval of the inverter). The equivalent circuit of the CFSI is shown in Fig. 1 (b). In the shoot through interval (or duty interval D) switch S is turned on along with both the switches of any inverter leg. In this interval source V g and capacitor Co charges inductor L together. In non-shoot through interval ((1- D) interval or D' interval), switches S is turned off which forces diodes Da and Db to tum on, and the inductor charges Co and power is delivered to the AC-Ioad through the inverter. The equivalent circuits of CFSI in D and D' intervals are shown in Fig. 1 (c). From Fig. 1 (c), the voltage across inductor L in one switching period of Ts is given by (1) (assuming small ripple approximation) from which the boost conversion ratio of CFSI can be obtained as shown in (2).

$$v_L = \begin{cases} V_g + V_c & During\ D.T_s \\ V_g - V_c & During\ (1-D).T_s \end{cases} \quad (1)$$

$$B_{CFSI} = \frac{V_c}{V_g} = \frac{1}{1-2D} \quad (2)$$



Current-Fed Switched Inverter (CFSI)

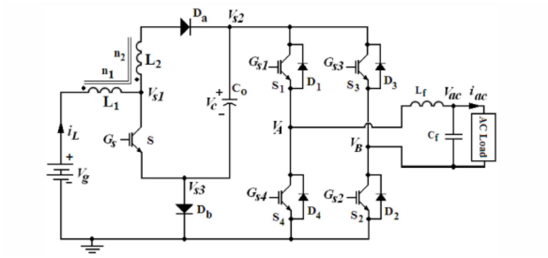


Equivalent circuit of CFSI

Although CFSI provides high boost output, use of shoot through state restricts the modulation index to a value always less than (1-D) in simple boost control method. This also imposes higher stress on the inverter switches. In the next section, a coupled inductor based CFSI topology (Trans-CFSI) will be derived which will mitigate the problems of CFSI as stated above.

III. DEVELOPEMENT OF TRANS-CFSI TOPOLOGY

The coupled inductor based CFSI topology, namely TransCFSI, It utilizes energy transfer through the transformer action of the coupled inductor to achieve high voltage boost which depends on the turns-ratio n1: n2.



Schematic of Trans-CFST topology

In the shoot through duty interval (D interval), switch S is turned on with the inverter leg being shorted while both the diodes remain reverse biased (as shown in Fig. 4 (a)). The inductor voltages in this interval can be written as in (3). In the non-shoot through duty interval ((1-D) interval), switch S is turned off and the inverter operates either in active or zero state. In this interval both the diodes remain in conduction (as shown in Fig. 4 (b)). The inductor voltages in (1-D) interval can be written as in (4).

$$\left.\begin{aligned} v_{L1} &= v_M = V_g + V_c \\ v_{L2} &= \frac{n_2}{n_1} v_{L1} = \frac{n_2}{n_1}(V_g + V_c) \end{aligned}\right| During\ D.T_s \quad (3)$$

$$\left.\begin{aligned} v_{L1} + v_{L2} &= v_L = V_g - V_c \\ v_M &= \frac{n_1}{n_1+n_2}(V_g - V_c) \end{aligned}\right| During\ (1-D).T_s \quad (4)$$

Applying volt-second balance [10] using (3) and (4), the boost factor of Trans-CFSI can be obtained as,

$$(V_g + V_c).D + \left(\frac{n_1}{n_1+n_2}(V_g - V_c)\right).(1-D) = 0$$

$$\Rightarrow B_{Trans-CFSI} \; \frac{V_c}{V_g} = \frac{1+nD}{1-(2+n)D} \quad (5)$$

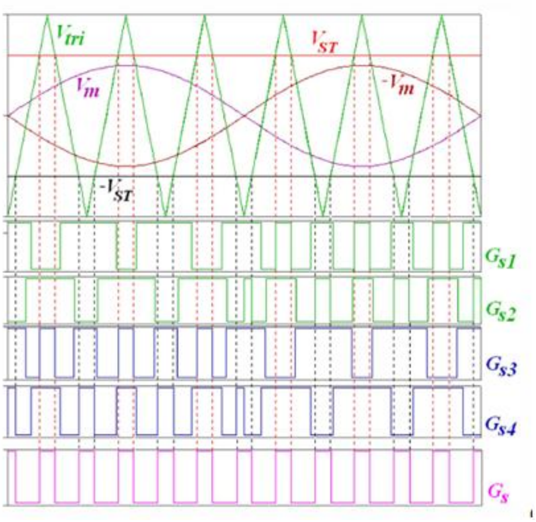
IV. PWM CONTROL SCHEME OF TRANS-CFSI

To incorporate shoot-through state in the PWM control, the traditional PWM technique for VSI is modified accordingly. The modified PWM scheme for Trans-CFSI is developed based on the traditional sine-triangle PWM with unipolar voltage switching, Sinusoidal modulation signals Vm(t) and –Vm(t) and high frequency carrier signal Vtri(t)Shoot-through constant voltages Vst and -Vst, and Gate signals Gs, G_{s1}, G_{s2} G_{S3}, G_{S4} of the modified modulation scheme for positive and negative half cycles of the sinusoidalmodulation signal Vm{t) is shown in Fig. 6 (a). Shoot-through signals STl and ST2 are generated by comparing Vsr and –Vsr with carrier signal. Thepositive and negative half-cycle of the modulation signal, respectively. In this half cycle, the shoot-through interval is inserted in the gate signals GS3 and GS4' Gate signals GS3, GS4, and Gs are generated using the following logic.

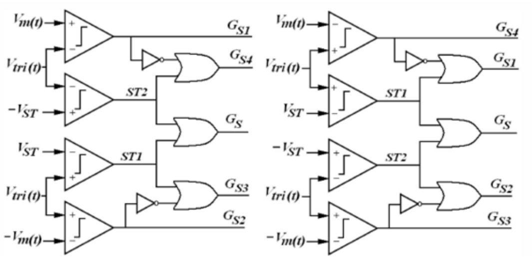
$$G_{S3} = \overline{G_{S2}} + ST1 \; ; \; G_{S4} = \overline{G_{S1}} + ST2 \; ; \; G_S = ST1 + ST2$$

Likewise, in the negative half-cycle (Vn(t)<0) of the modulation signal, gate signals G_{S3} and $G_{S4}$are generated by comparing the sinusoidal modulation signals –Vn(t) and Vn(t) with carrier signal V_{tri}(t). The shoot-through interval is inserted in gate signals $G_{s1}$and G_{S2}. Gate signals G_{s1}, $G_{s2}$and Gs are generated using the following logic equation.

$$G_{S1} = \overline{G_{S4}} + ST1 \; ; \; G_{S2} = \overline{G_{S3}} + ST2 \; ; \; G_S = ST1 + ST2$$



Generation of PWM control signals



PWM control schemewhen Vm(t) > O, PWM control schemewhen Vm(t) < O

PWM control signals for the positive half-cycle of the modulation signal.

V. SIGNALS & DATA TRANSFER:

In complicated block diagrams, there may arise the need to transfer data from one portion to another portion of the block. They may be in different subsystems. That signal could be dumped into a goto block, which is used to send signals from one subsystem to another.

Multiplexing helps us remove clutter due to excessive connectors, and makes matrix (column/row) visualization easier.

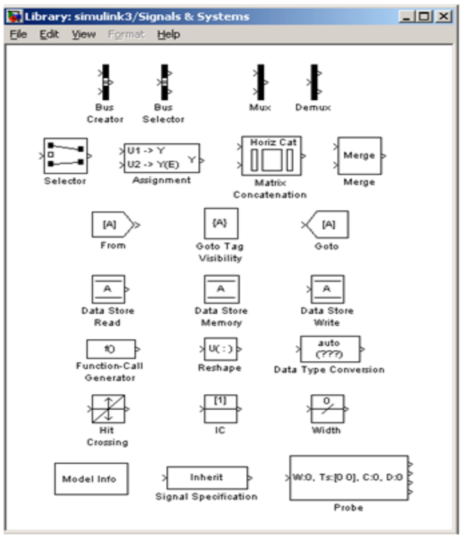


fig signals and systems

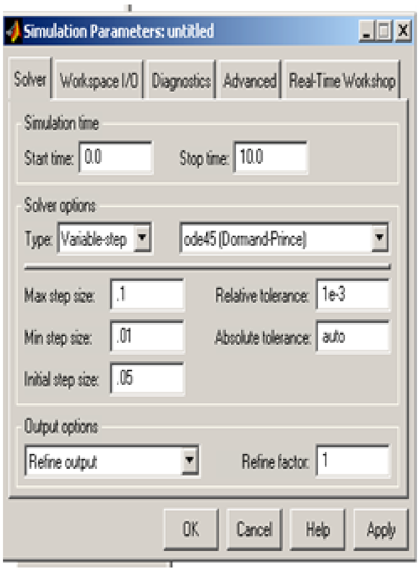
Making subsystems

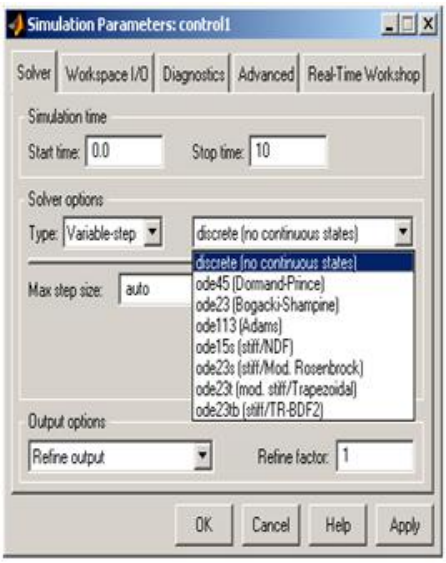
Drag a subsystem from the Simulink Library Browser and place it in the parent block where you would like to hide the code. The type of subsystem depends on the purpose of the block. In general one will use the standard subsystem but other subsystems can be chosen. For instance, the subsystem can be a triggered block, which is enabled only when a trigger signal is received.

Open (double click) the subsystem and create input / output PORTS, which transfer signals into and out of the subsystem. The input and output ports are created by dragging them from the Sources and Sinks directories respectively. When ports are created in the subsystem, they automatically create ports on the external (parent) block. This allows for connecting the appropriate signals from the parent block to the subsystem.

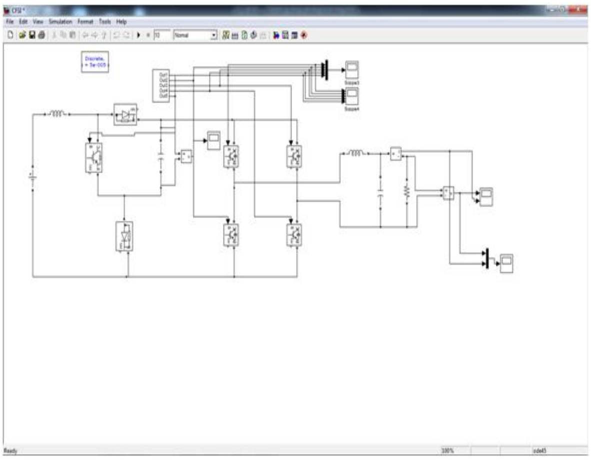
Setting simulation parameters:

Running a simulation in the computer always requires a numerical technique to solve a differential equation. The system can be simulated as a continuous system or a discrete system based on the blocks inside. The simulation start and stop time can be specified. In case of variable step size, the smallest and largest step size can be specified. A Fixed step size is recommended and it allows for indexing time to a precise number of points, thus controlling the size of the data vector. Simulation step size must be decided based on the dynamics of the system. A thermal process may warrant a step size of a few seconds, but a DC motor in the system may be quite fast and may require a step size of a few milliseconds.

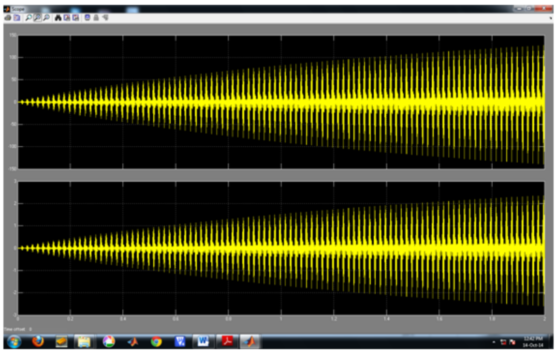




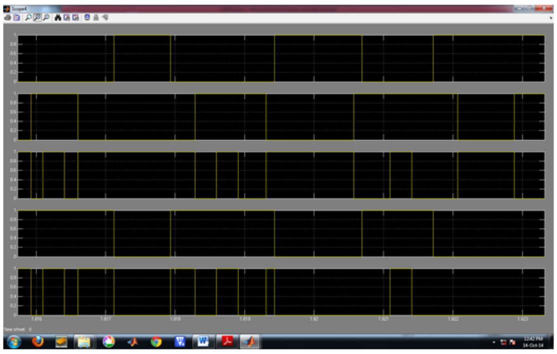
VI. MATLAB MODEL



VII. SCREEN SHOTS



Output voltage and current



Pulses to ifsi

VIII. CONCLUSION

This paper proposed a coupled inductor based high boost inverter, named Trans-CFSI, which exhibits improved EMI noise immunity similar to the ZSI, SBI etc. The high gain of the inverter is obtained by the transformer action of the coupled inductor and insertion of shoot-through state. In this paper the development of Trans-CFSI topology is described in details along with its steady-state characteristics and PWM switching scheme. The proposed inverter is tested on a Laboratory prototype and verified. The inverter is also tested.

IX. REFERENCES

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